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| <b>(54) Title:</b> USES OF 1,2,2,3,3-PENTAFLUOROPROPANE<br><br><b>(57) Abstract</b><br><br>1,2,2,3,3-pentafluoropropane is used as a refrigerant, a cleaning agent, an aerosol propellant, a heat transfer media, a gaseous dielectric, a fire extinguishing agent, an expansion agent for polymers such as polyolefins and polyurethanes, and as a power cycle working fluid.   |           |   |

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TITLE

USES OF 1,2,2,3,3-PENTAFLUOROPROPANE

FIELD OF INVENTION

10           This invention relates to the use of  
1,2,2,3,3-pentafluoropropane (HFC-245ca) as a refrigerant,  
an aerosol propellant, a cleaning agent, a heat transfer  
media, a gaseous dielectric, a fire extinguishing agent, an  
expansion agent for polymers such as polyolefins and  
15 polyurethanes, and as a power cycle working fluid. More  
particularly, it relates to the use of 1,2,2,3,3-  
pentafluoropropane as a highly effective and potentially  
environmentally safe refrigerant in refrigeration equipment  
that uses centrifugal compression.

20

BACKGROUND OF THE INVENTION

Mechanical refrigeration is primarily an  
application of thermodynamics wherein a cooling medium, such  
as a refrigerant, goes through a cycle so that it can be  
25 recovered for reuse. Commonly used cycles include vapor-  
compression, absorption, steam-jet or steam-ejector, and  
air.

The equipment used in a vapor-compression cycle  
includes an evaporator, a compressor, a condenser, a liquid  
30 storage receiver and an expansion valve. Liquid refrigerant  
enters the evaporator through an expansion valve, and the  
liquid refrigerant boils in the evaporator at a low  
temperature to form a gas to produce cooling. The low  
pressure gas enters a compressor where the gas is compressed  
35 to raise its pressure and temperature. The high pressure  
gaseous refrigerant then enters the condenser in which the  
refrigerant condenses and discharges its heat to the  
environment. A receiver collects the condensed high  
pressure liquid refrigerant, and the refrigerant goes to the  
40 expansion valve through which the liquid expands from the

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5 high pressure level in the condenser to the low pressure level in the evaporator.

There are various types of compressors that may be used in refrigeration applications. Compressors can be generally classified as reciprocating, rotary, jet,  
10 centrifugal, or axial-flow, depending on the mechanical means to compress the fluid, or as positive-displacement or dynamic, depending on how the mechanical elements act on the fluid to be compressed.

A centrifugal compressor uses rotating elements to  
15 accelerate the refrigerant radially, and typically includes an impeller and diffuser housed in a casing. Centrifugal compressors usually take fluid in at an impeller eye, or central inlet of a circulating impeller, and accelerate it radially outwardly. Some static pressure rise occurs in the  
20 impeller, but most of the pressure rise occurs in the diffuser section of the casing, where velocity is converted to static pressure. Each impeller-diffuser set is a stage of the compressor. Centrifugal compressors are built with from 1 to 12 or more stages, depending on the final pressure  
25 desired and the volume of refrigerant to be handled.

The pressure ratio, or compression ratio, of a compressor is the ratio of absolute discharge pressure to the absolute inlet pressure. Pressure delivered by a centrifugal compressor is practically constant over a  
30 relatively wide range of capacities.

Multistage centrifugal compressors can handle 500 to more than 150,000 cfm of refrigerant (14 to 4300 m<sup>3</sup>/m) at pressures as high as 5000 psi (35 MPa), but are limited to compression ratios in the order of 10.

35 Positive displacement compressors draw vapor into a chamber, and the chamber decreases in volume to compress the vapor. After being compressed, the vapor is forced from the chamber by further decreasing the volume of the chamber to zero or nearly zero. A positive displacement compressor  
40 can build up a pressure which is limited only by the

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- 5 volumetric efficiency and the strength of the parts to withstand the pressure.

Unlike a positive displacement compressor, a centrifugal compressor depends entirely on the centrifugal force of the high speed impeller to compress the vapor  
10 passing through the impeller. There is no positive displacement, but rather what is called dynamic-compression.

The pressure a centrifugal compressor can develop depends on the tip speed of the impeller. Tip speed is the speed of the impeller measured at its tip and is related to  
15 the diameter of the impeller and its revolutions per minute. The capacity of the centrifugal compressor is determined by the size of the passages through the impeller. This makes the size of the compressor more dependent on the pressure required than the capacity.

20 Because of its high speed operation, a centrifugal compressor is fundamentally a high volume, low pressure machine. A centrifugal compressor works best with a low pressure refrigerant, such as trichlorofluoromethane (CFC-11). When CFC-11 is used as the refrigerant, suction  
25 pressure in the compressor is from about 18 to 25 inches of vacuum depending on the evaporator temperature required, and the discharge pressure is near atmospheric pressure. A single stage impeller can be used with CFC-11 for air conditioning suction temperatures.

30 A two-stage impeller is common for many conditions. In operation, the discharge of the first stage impeller goes to the suction intake of a second impeller. Each stage can build up a compression ratio of about 4 to 1, that is, the absolute discharge pressure can be 4 times the  
35 absolute suction pressure.

Centrifugal compressors range in size from 200 to 10,000 kilowatts of refrigeration capacity. For applications requiring more or less refrigeration capacity than CFC-11, 1,2,2-trichloro-trifluoroethane (CFC-113) or  
40 1,2-dichloro-tetrafluoroethane (CFC-114) can be used as the

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5 refrigerant in place of CFC-11 without changing the  
compressor except for providing a properly-sized motor.

A proposed world-wide reduction in the production  
of fully halogenated chlorofluorocarbons such as CFC-11,  
CFC-113, and CFC-114, has developed an urgent need for  
10 alternative, more environmentally acceptable products.

Large investments have been made in centrifugal  
compressors that were designed for CFC-11, CFC-113, or CFC-  
114. A centrifugal compressor is designed for the  
refrigerant with which it is to be used. That is, a  
15 centrifugal compressor is typically designed by first  
selecting a refrigerant, and then determining the desired  
refrigeration capacity and power source. Once these  
variables are known, the diameter of the impeller, the size  
of the impeller opening, and the number of stages are  
20 designed to achieve the desired refrigeration capacity.

A problem with replacing chlorofluorocarbons with  
alternative refrigerants for use in existing centrifugal  
compressors is that unless the alternative refrigerant  
matches certain physical criteria, the alternative  
25 refrigerant will not work in the existing centrifugal  
compressor. Important criteria include the "tip speed" of a  
refrigerant, meaning the speed of the impeller as measured  
at its tip for a given centrifugal compressor, and the  
density and molecular weight of the refrigerant.

30 If it is desired to replace a refrigerant in a  
centrifugal compressor, and the replacement refrigerant does  
not perform as well as the original refrigerant, it is  
possible to design a compressor for the replacement  
refrigerant and to replace the original compressor.

35 However, replacing an existing compressor is not possible in  
all cases. For example, a centrifugal compressor may be so  
large (such as is used in the cooling systems of large  
buildings) that it cannot be replaced by a redesigned  
compressor. In such cases, the replacement refrigerant must  
40 work in the original compressor.

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SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a refrigerant that may be used in centrifugal compressors designed for the refrigerants trichlorofluoromethane (CFC-11), 1,1,2-trichloro-  
10 trifluoroethane (CFC-113) or 1,2-dichloro-tetrafluoroethane (CFC-114) that performs similarly to CFC-11, CFC-113 or CFC-114.

It is another object of this invention to provide a refrigerant that has a lower ozone depletion potential  
15 than CFC-11, CFC-113 or CFC-114.

These and other objects are achieved by the discovery that 1,2,2,3,3 pentafluoropropane (HFC-245ca) can be used as a refrigerant in centrifugal compression refrigeration equipment designed for CFC-11, CFC-113, or  
20 CFC-114 while achieving operating performances comparable to CFC-11, CFC-113 or CFC-114.

The present invention also relates to the discovery that HFC-245ca may be used as an aerosol propellant, a cleaning agent, a heat transfer media, a  
25 gaseous dielectric, a fire extinguishing agent, an expansion agent for polymers such as polyolefins and polyurethanes, or as a power cycle working fluid.

DETAILED DESCRIPTION

30 The present invention relates to the use of 1,1,2,2,3-pentafluoropropane (HFC-245ca) as a refrigerant for use in centrifugal compression refrigeration equipment.

As early as the 1970's with the initial emergence of a theory that the ozone was being depleted by chlorine  
35 atoms introduced to the atmosphere from the release of fully halogenated chlorofluorocarbons, it was known that the introduction of hydrogen into previously fully halogenated chlorofluorocarbons markedly reduced the chemical stability of these compounds. Hence, these now destabilized compounds

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5 would be expected to degrade in the atmosphere and not reach the stratosphere and the ozone layer.

The accompanying Table 1 lists the ozone depletion potential of some fully and partially halogenated halocarbons. Halocarbon Global Warming Potential data  
 10 (potential for reflecting infrared radiation (heat) back to earth and thereby raising the earth's surface temperature) are also shown.

Ozone Depletion Potential (ODP) is based on the ratio of the calculated ozone depletion in the stratosphere  
 15 resulting from the emission of a compound compared to the ozone depletion potential resulting from the same rate of emission of CFC-11, which is set at 1.0. HFC-245ca ( $\text{CF}_2\text{HCF}_2\text{CFH}_2$ ) does not contain any chlorine therefore it has an Ozone Depletion Potential (ODP) of 0 as compared with  
 20 CFC-11.

TABLE 1  
 OZONE DEPLETION AND GREENHOUSE POTENTIALS

| 25 | <u>Refrigerant</u>                                   | Ozone Depletion<br><u>Potential</u> | Halocarbon<br>Global Warming |
|----|--|-------------------------------------|------------------------------|
|    |  |                                     | <u>Potential</u>             |
|    | CFC-11 ( $\text{CFCl}_3$ )                           | 1.0                                 | 1.0                          |
|    | CFC-113 ( $\text{CCl}_2\text{FCClF}_2$ )             | 0.8                                 | 1.4                          |
|    | CFC-114 ( $\text{CClF}_2\text{CClF}_2$ )             | 0.7                                 | 3.9                          |
|    | HCFC-245ca ( $\text{CFH}_2\text{CF}_2\text{CHF}_2$ ) | 0.0                                 | *                            |

30

\*Due to the number of hydrogen atoms present in the HFC-245ca molecule, the global warming potential should be negligible when compared with a fully halogenated CFC refrigerants such as CFC-11, CFC-113 or CFC-114.

35

It should be noted that 1,1,2,2,3-pentafluoropropane is the same isomer as 1,2,2,3,3-pentafluoropropane.

Although 1,2,2,3,3-pentafluoropropane has zero ODP and an expected minimal global warming potential, it is an

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- 5 extremely effective refrigerant and performs similarly to chlorofluorocarbon refrigerants.

There are three important choices in selecting or designing a centrifugal compressor: the diameter of the impeller, which means the length from the end of one of the  
10 impeller blades to the end of an opposite blade, the width of the passage in the impeller, and the refrigerant. The impeller and refrigerant must be selected in a combination that best suits a desired application.

The diameter of the impeller depends on the  
15 discharge pressure that must be achieved. For a given rotative speed, a large impeller diameter provides a higher tip speed, which results in a higher pressure ratio. Tip speed means the tangential velocity of the refrigerant leaving the impeller.

20 If a centrifugal compressor is driven by an electric motor operating at 60 radians per second (r/s), the impeller diameter needed for the 113.1 m/s tip speed of CFC-11 is 0.6 meters.

It is desirable to find a "drop-in" replacement  
25 for CFC-11, that is, a refrigerant that may be used in equipment designed for CFC-11 and that performs similarly to CFC-11. To perform as well as CFC-11 in existing equipment, a refrigerant must be such that when it is used, the impeller achieves a tip speed that matches, or nearly  
30 matches, the tip speed of the impeller when CFC-11 is used. HFC-245ca provides a tip speed identical or nearly identical to the tip speed of CFC-11 when the two refrigerants are used in the same operating equipment. Another important factor in the design of a centrifugal compressor is the  
35 width of passage in the impeller. Increasing the size of this passage increases the capacity of the compressor, but also increases the power required by the compressor. Centrifugal compressors are designed to maintain high efficiencies, especially when the compressors are used with  
40 machines that operate at low capacities. One way to



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5 increase the efficiency of the compressor without increasing the width between the impeller blades is to use a refrigerant with a low density, such as CFC-11 or CFC-113, which reduces the friction on the narrow impeller faces relative to the flowrate through the impeller.

10 The liquid density of CFC-11 is 1.487 g/cc at room temperature, and the liquid density of 1,2,2,3,3-pentafluoropropane is 1.377 g/cc at room temperature. The lower density of HFC-245ca may increase the efficiency of a centrifugal compressor at low capacities, and at least  
15 should allow the centrifugal compressor to operate at the same efficiency as when CFC-11 is used.

Finally, the molecular weight of the refrigerant is an important design consideration for centrifugal compressors. The molecular weight of CFC-11 is 137.4 and  
20 the molecular weight of 1,2,2,3,3-pentafluoropropane is essentially identical, 134.0.

HFC-245ca was considered a flammable refrigerant based on the number of hydrogen atoms present in the molecule. Recently flammability measurements were performed  
25 according to the ASTM E-681-85 technique and found HFC-245ca to be nonflammable in air at room temperature and pressure. However, it may be possible that HFC-245ca may become combustible if under pressure in the presence of air and an ignition source.

### 30 EXAMPLE 1

#### Tip Speed to Develop Pressure

Tip speed can be estimated by making some fundamental relationships for refrigeration equipment that uses centrifugal compressors. The torque a impeller ideally  
35 imparts to a gas is defined as

$$T = m \cdot (v_2 \cdot r_2 - v_1 \cdot r_1) \quad \text{Equation 1}$$

where

T = torque, N\*m

m = mass rate of flow, kg/s

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5  $v_2$  = tangential velocity of refrigerant leaving impeller,  
m/s

$r_2$  = radius of exit impeller, m

$v_1$  = tangential velocity of refrigerant entering impeller,  
m/s

10  $r_1$  = radius of inlet of impeller, m

Assuming the refrigerant enters the impeller in an essentially radial direction, the tangential component of the velocity  $v_1 = 0$ , therefore

$$T = m \cdot v_2 \cdot r_2 \quad \text{Equation 2}$$

15 The power required at the shaft is the product of the torque and the rotative speed

$$P = T \cdot \omega \quad \text{Equation 3}$$

where

$P$  = power, W

20  $\omega$  = rotative speed, rad/s  
therefore,

$$P = T \cdot \omega = m \cdot v_2 \cdot r_2 \cdot \omega \quad \text{Equation 4}$$

At low refrigerant flow rates, the tip speed of the impeller and the tangential velocity of the refrigerant  
25 are nearly identical; therefore

$$r_2 \cdot \omega = v_2 \quad \text{Equation 5}$$

and

$$P = m \cdot v_2 \cdot v_2 \quad \text{Equation 6}$$

30 Another expression for ideal power is the product of the mass rate of flow and the isentropic work of compression,

$$P = m \cdot H_i \cdot (1000 \text{ J/kJ}) \quad \text{Equation 7}$$

where

35  $H_i$  = Difference in enthalpy of the refrigerant from a saturated vapor at the evaporating conditions to saturated condensing conditions, kJ/kg.

Combining the two expressions Equation 6 and 7 produces,

40  $v_2 \cdot v_2 = 1000 \cdot H_i \quad \text{Equation 8}$

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5           Although equation 8 is based on some fundamental assumptions, it provides a good estimate of the tip speed of the impeller and provides an important way to compare tip speeds of refrigerants.

10           Table 1 shows theoretical tip speeds that are calculated for trichlorofluoromethane (CFC-11), 1,2,2,3,3-pentafluoropropane (HFC-245ca), and ammonia. The conditions assumed for this comparison are that the refrigerant is compressed from a saturated vapor at 10 deg Celsius (50 degrees Fahrenheit) to a pressure corresponding to a  
15           condensing temperature of 30 degrees Celsius (86 degrees Fahrenheit). These are typical conditions under which centrifugal chillers perform.

Table 2

|                                 | <u>CFC-11</u> | <u>HFC-245ca</u> | <u>Ammonia</u> |
|---------------------------------|---------------|------------------|----------------|
| 20       H <sub>i</sub> , kJ/kg | 12.8          | 13.5             | 88.0           |
| v <sub>2</sub> , m/s            | 113.1         | 116.2            | 297.0          |

25           Example 1 shows that if HFC-245ca is substituted for CFC-11 in a centrifugal compressor operating at the same speed as when CFC-11 is used (60 r/s), the impeller diameter needed to achieve a tip speed of 116.2 m/s is 0.62 meters. Because the impeller diameters necessary when CFC-11 or HFC-245ca are used in the compressor are so similar (0.6 m v.  
30       0.62 m), little or no modification to the impeller would be needed if HFC-245ca is substituted for CFC-11.

          If another refrigerant such as ammonia were used in the equipment designed for CFC-11, the equipment would require an impeller diameter of 1.58 meters. Therefore,  
35       ammonia could not be used in equipment designed for CFC-11 because the impeller diameter of that equipment would need to be increased to 1.58 meters for the equipment to perform as well with ammonia as it performs with CFC-11. An  
40       impeller of 1.58 meters is impractical because it would require a compressor that is 2.6 times larger than a

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- 5 compressor that uses CFC-11 and because the strength of the material used in typical impellers limits the speed of the impeller to 300 m/s. The tip speed of 297 m/s that would be necessary if ammonia were used is very close to the strength limitations of conventional impellers.
- 10 If ammonia were used in equipment designed for use with CFC-11, that equipment would not achieve a tip speed high enough for the compressor to achieve a pressure necessary for condensation to take place.

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EXAMPLE 2Standard Test Method for Concentration Limits  
of Flammability of Chemicals

ASTM E-681-85

This test method covers the determination of the  
lower and upper concentration limits of flammability of  
chemicals having sufficient vapor pressure to form flammable  
mixtures in air at one atmosphere at a test temperature.  
This method may be used to determine these limits in the  
presence of inert dilution gases. No oxidant stronger than  
air should be used.

A uniform mixture of a gas or vapor with air is  
ignited in a closed 5 liter glass vessel and the upward and  
outward propagation of the flame away from the ignition  
source (a spark source and match head) is noted by visual  
observation. The concentration of the flammable component  
is varied between trials until the composition which just  
sustains propagation of the flame is determined.

Various concentrations of HFC-245ca were mixed  
with air and none were found to have a propagating flame  
that either was sustained or reached the walls of the 5  
liter flask.

Table 2

|    |                 |                           |                        | Propagating  |
|----|-----------------|---------------------------|------------------------|--------------|
| 30 | <u>Test no.</u> | <u>Flask Temp (deg C)</u> | <u>Vol % HFC-245ca</u> | <u>Flame</u> |
|    | 1               | 23                        | 10.0                   | No           |
|    | 2               | 23                        | 12.5                   | No           |
|    | 3               | 23                        | 7.5                    | No           |
|    | 4               | 23                        | 5.0                    | No           |
| 35 | 5               | 23                        | 11.0                   | No           |
|    | 6               | 23                        | 9.0                    | No           |

The largest visual flame seen was during Test 1  
which had a flame approximately 1 inch wide and 5 inches  
long that became very short and was not sustained.

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5 Additional tests 2, 5, and 6 were run to ensure this flame  
was not longer or sustained. Tests 2, 5, and 6 found  
smaller flames, that is flames 1/2 inch wide and 1 to 2  
inches high that did not last as long as test 1. Tests 3  
and 4 were run to ensure that the lower flammability limit  
10 was not missed. The conclusion from these tests was that  
1,2,2,3,3-pentafluoropropane is nonflammable at atmospheric  
pressure and temperature according to the ASTM E-681-85.

HFC-245ca could be used as a new cleaning agent,  
aerosol propellant, heat transfer media, gaseous dielectric,  
15 fire extinguishing agent, expansion agent for polymers such  
as polyolefins and polyurethanes, and power cycle working  
fluids.

A process for cleaning a solid surface includes  
treating said surface with HFC-245ca.

20 A process for preparing a polymer foam from a  
polymer foam formulation includes utilizing an effective  
amount of 1,2,2,3,3-pentafluoropropane.

A process for preparing aerosol formulations  
includes combining active ingredients in an aerosol  
25 container with an effective amount of 1,2,2,3,3-  
pentafluoropropane.

A process for atomizing a fluid includes a step of  
using 1,2,2,3,3-pentafluoropropane as an aerosol propellant.

A process for electrically insulating includes a  
30 step of using 1,2,2,3,3-pentafluoropropane as a gaseous  
dielectric.

A process for suppressing a fire includes a step  
of using 1,2,2,3,3-pentafluoropropane as a fire  
extinguishing agent.

35 A process for delivering power includes a step of  
using 1,2,2,3,3-pentafluoropropane as a power cycle working  
fluid.

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CLAIMS

- 5
1. A centrifugal compressor designed for use with a refrigerant selected from the group consisting of trichlorofluoromethane, 1,2,2-trichloro-trifluoroethane and 1,2-dichloro-tetrafluoroethane, wherein the refrigerant used  
10 in the compressor is 1,2,2,3,3-pentafluoropropane.
2. The compressor of claim 1, wherein the output temperature of the compressor is less than 100 degrees Celsius.
- 15
3. A refrigerant for use with a centrifugal compressor designed for use with a refrigerant selected from the group consisting of trichlorofluoromethane, 1,2,2-trichloro-trifluoroethane and 1,2-dichloro-  
20 tetrafluoroethane, wherein the refrigerant comprises 1,2,2,3,3-pentafluoropropane.
4. A process for preparing a polymer foam from a polymer foam formulation utilizing an effective amount of  
25 1,2,2,3,3-pentafluoropropane.
5. A process for preparing aerosol formulations wherein active ingredients are combined in an aerosol container with an effective amount of 1,2,2,3,3-  
30 pentafluoropropane.
6. A process for atomizing a fluid comprising a step of using 1,2,2,3,3-pentafluoropropane as an aerosol propellant.
- 35
7. A process for electrically insulating comprising a step of using 1,2,2,3,3-pentafluoropropane as a gaseous dielectric.

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5           8. A process for suppressing a fire comprising a step of using 1,2,2,3,3-pentafluoropropane as a fire extinguishing agent.

10           9. A process for delivering power comprising a step of using 1,2,2,3,3-pentafluoropropane as a power cycle working fluid.

15           10. A process for cleaning a solid surface comprises treating said surface with 1,2,2,3,3-pentafluoropropane.